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# NOTES

## Effects of Rainbow Trout Predation on Little Colorado Spinedace

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*Abstract.*—We tested the effect of predation by rainbow trout *Oncorhynchus mykiss* on the behavior and spatial distribution of Little Colorado spinedace *Lepidomeda vittata*, a native cyprinid that occurs in disjunct populations in northern Arizona. Field experiments demonstrated high predation on Little Colorado spinedace even in the presence of natural refuges and abundant macroinvertebrate prey. Little Colorado spinedace showed almost no predator avoidance in the presence of rainbow trout, which implies limited interaction with large nonnative predators through evolutionary time. Results suggest that rainbow trout may have a significant influence on the habitat use, behavior, and geographic distribution of Little Colorado spinedace, and may be responsible, in part, for the disjunct geographic distribution of this threatened native fish species.

The Little Colorado spinedace *Lepidomeda vittata* is a native cyprinid that occurs only in disjunct populations in the Little Colorado River system in Coconino, Navajo, and Apache counties, Arizona. This species inhabits a wide range of habitats, including stagnant pools and permanent flowing waters, and is found over substrates varying from fine sediments to bedrock (Miller 1963; Minckley and Carufel 1967; Minckley 1984; Marsh and Young 1988; Blinn and Runck 1990). Early reports (Miller 1963; Minckley and Carufel 1967) showed that the Little Colorado spinedace was abundant in localized sections of East Clear Creek, a Little Colorado River watershed in Coconino County. More recent surveys have shown that the numbers of Little Colorado spinedace are very low in East Clear Creek, and the largest and most stable populations located in the lower sections of Nutrioso and Chevelon creeks (Minckley 1984; Marsh and Young 1988; Blinn and Runck 1990; B. Palmer, Arizona Game and Fish, personal communication). These data implicating the diminishing numbers and range of the Little Colorado spinedace led to the species' listing as threatened by the Endangered Species Committee of the American Fisheries Society (Williams et al. 1989). The definition of "threatened" (i.e., likely to become endangered in the foreseeable future) is the same as that used in the U.S. Endangered Species Act of 1973.

Minckley and Carufel (1967) suggested that reductions in streamflow, repeated use of ichthyiotoxins, and interactions with introduced fish species had contributed to the decline of the Little Colorado spinedace. More recently, Minckley (1983), Meffe (1985), and Rinne and Minckley (1991) proposed that predation plays a major role in the overall decline of native southwestern fishes.

Nutrioso Creek provides an opportunity to test the interactions between Little Colorado spinedace and rainbow trout *Oncorhynchus mykiss*, because the two species show an inverse relationship in distribution over a relatively short distance (40 km). Typically, rainbow trout occupy the upper 10 km of Nutrioso Creek, and Little Colorado spinedace reside in the lower 30 km, with minimal overlap between the two species (Minckley 1984; Marsh and Young 1988; Blinn and Runck 1900; Palmer, personal communication).

We propose that rainbow trout may be instrumental in delimiting both the intrastream (habitat) and interstream (geographic) distributions and the ultimate survival of Little Colorado spinedace. Accordingly, we tested the effect of predation by rainbow trout on Little Colorado spinedace using natural refuges in Nutrioso Creek. We also determined intrastream distribution by Little Colorado spinedace in the presence of rainbow trout.

## Study Site

Nutrioso Creek is a first–third-order stream in eastern Arizona that drains the northern slopes of the White Mountains in Apache County. The headwaters of this small perennial stream (0.5–2.5 m wide, 0.1–1.0 m deep) originate at an altitude of 2,480 m in a spruce–fir forest. The stream meanders through treeless alpine meadows for about 40 km where it eventually joins the Little Colorado River (<2,090 m). Upper reaches (first 10 km) consist of cobble riffles and maintain relatively low temperatures (<20°C) and clear water (mean absorption coefficient, 0.59; SE, 0.04), whereas lower reaches consist of pools with organic-rich sediments, relatively high temperatures (>25°C) and turbid water (mean absorption coefficient, 1.81; SE, 0.17) during the summer (Blinn and Runck 1990). Furthermore, dissolved oxygen concentrations in the upper reaches of Nutrioso Creek are typically 7.5 mg/L or higher over a diel period, but drop to less than 1.5 mg/L at night in deep pools in lower reaches (Blinn and Runck 1990).

## Methods

*Field predation experiments.*—Four experimental enclosures (2 m wide × 3 m long) were constructed in the upper reach of Nutrioso Creek with strips of hardware cloth (64-mm mesh, 61 cm high) stretched across the width (1.5–2.0 m) of the stream and secured by 1.5-m steel posts. Each enclosure included the full range of habitats available in Nutrioso Creek including a pool and riffle and natural refuges (i.e., rock, vegetation, and undercut stream bank).

All experimental enclosures received a mean of 3.8 (SE, 0.5) Little Colorado spinedace/m$^2$ (40–65 mm total length, TL); fish were acclimated for 24 h prior to the introduction of rainbow trout. Two treatment enclosures received 0.3 to 0.6 rainbow trout/m$^2$ (190–270 mm TL) and two control enclosures received no rainbow trout. Predator and prey densities were comparable to those for rainbow trout in the upper reaches of Nutrioso Creek and localized densities of Little Colorado spinedace in mid-to-lower reaches (Blinn and Runck 1990). Exposure times for in situ experiments averaged 10 d, after which the number of Little Colorado spinedace within each enclosure were recorded. The stomach contents of rainbow trout ($N$ = 6) from the enclosures were examined for the presence of Little Colorado spinedace. The experiment was replicated on three dates and new rainbow trout and Little Colorado spinedace were used on each date. Also, a short-term (24-h) experiment was conducted to determine the number of spinedace consumed by rainbow trout ($N$ = 4). The number of replicates for all experiments was kept to a minimum because of the endangered status of Little Colorado spinedace. (All fish were collected on permit PRT 676-811-AGFD.)

The proportions of Little Colorado spinedace missing from each enclosure were arcsine-transformed for statistical analyses (Zar 1984). The effect of rainbow trout (two treatment levels) on the proportion of spinedace missing was tested with a one-way fixed effects analysis of variance (ANOVA). Macroinvertebrates were estimated from two Surber samples taken from each enclosure at the end of each experiment to determine the food base available to the rainbow trout.

*Field behavior experiments.*—Observations on the behavior of Little Colorado spinedace in the presence of rainbow trout were conducted in the same enclosures described above on separate dates from predation experiments. Each enclosure had four potential habitats (mean area); instream emergent vegetation (*Phalaris* sp.; 0.19 m$^2$; SE, 0.02), large boulder (0.13 m$^2$; SE, 0.03), undercut bank (0.36 m$^2$; SE, 0.08), and open water. These habitats were available in similar proportions in Nutrioso Creek. A mean of 26 (SE, 2.7) Little Colorado spinedace (40–65 mm TL) were placed in each enclosure; fish were acclimated for 24 h prior to the introduction of rainbow trout. Half of the enclosures received rainbow trout (2 fish/enclosure; 200–260 mm TL) and half received no rainbow trout.

The number of Little Colorado spinedace using each of the four habitats in each enclosure was determined at 1-min intervals during 10-min observation periods from the stream bank. Observation periods were conducted during 0630–0900 hours, 1130–1330 hours, and 1700–1930 hours. Each time period included at least 40 min of observation per treatment per date.

The proportions of Little Colorado spinedace using each habitat were arcsine-transformed for statistical analyses (Zar 1984). A one-way, fixed effects ANOVA was used to determine if time of day had an effect on habitat use by spinedace. The effect of rainbow trout (two treatment levels) and date of observation (three treatment levels) on habitat use (four treatment levels) by spinedace was tested with a three factor, fixed effects multiple analysis of variance (MANOVA). The Student–Newman–Keuls multiple-range test (Zar

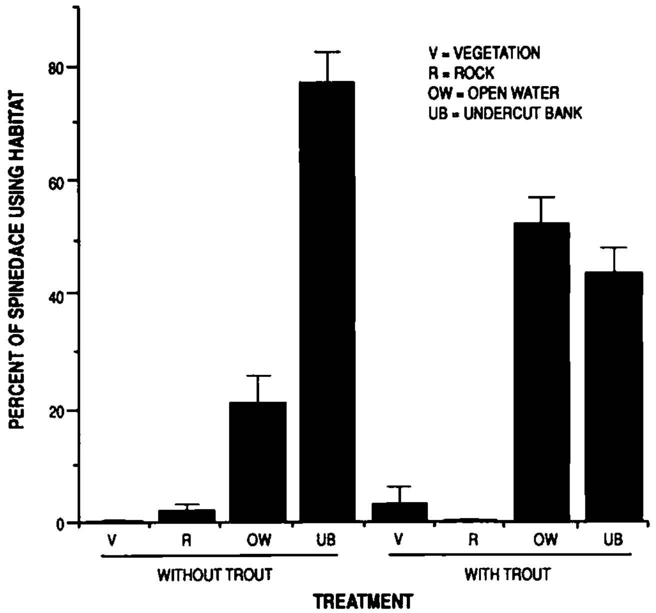


FIGURE 1.—Mean (+SE) percent habitat utilization by Little Colorado spinedace in enclosure treatments with and without rainbow trout in Nutrioso Creek, Arizona.

1984) was used to compare treatment means when significant main effects and interaction effects were indicated by MANOVA.

## Results and Discussion

Rainbow trout consumed Little Colorado spinedace in field experiments where there were rock and vegetation refuges, and in the presence of abundant macroinvertebrate prey. Significantly more ($F$ = 17.7; df = 1,10; $P$ = 0.002) Little Colorado spinedace disappeared from experimental enclosures containing rainbow trout (mean, 34%; SE, 0.6) than from control enclosures without rainbow trout (mean, 5%; SE, 0.2). Furthermore, rainbow trout in enclosures typically had Little Colorado spinedace in the their stomachs (mean, 0.7 spinedace/rainbow trout stomach; SE, 0.2) at the end of the experiment. In a short-term experiment, one rainbow trout (185 mm TL) consumed four Little Colorado spinedace (mean, 48 mm TL; SE, 1.6) within 16 h. A mean of 0.6 (SE, 0.03) Little Colorado spinedace were consumed each day during the 10-d field experiments. There was a significant difference in the average size (mean, 53.2 mm; SE, 0.63) of Little Colorado spinedace consumed by rainbow trout and those remaining (mean, 63.7 mm; SE, 1.5) in the treatment enclosures with rainbow trout ($t$ = 5.41; df = 56; $P$ < 0.01).

The loss of Little Colorado spinedace in enclosures without rainbow trout resulted from predators such as snakes and belostomatid insects. Although captures by snakes occur infrequently, we did observe a 540-mm garter snake (*Thamnophis* sp.) capture a rainbow trout (125 mm TL) within an enclosure. Blinn and Runck (1990) also demonstrated that belostomatids are active predators on Little Colorado spinedace. Belostomatids (about 0.6/m$^2$) were found in the enclosures, and empty carcasses of Little Colorado spinedace were observed on two occasions.

Although natural macroinvertebrate prey were abundant in the enclosures, rainbow trout fed on Little Colorado spinedace. Typically rainbow trout, especially juveniles, feed on bottom-dwelling and terrestrial insects in lotic ecosystems (Carlander 1969; Angradi and Griffith 1990). We calculated a mean of 17,866 (SE, 283) macroinvertebrates/m$^2$ within the enclosures during the predation experiments. This included a wide variety of organisms, with Elmidae adults and larvae (5,433/m$^2$), Plecoptera (4,300/m$^2$), Ephemeroptera (3,699/m$^2$), Diptera larvae (2,267/m$^2$), Trichoptera (1,367/m$^2$), Hydracarina (400/m$^2$), and Oligochaeta (167/m$^2$) accounting for most of the macroinvertebrates.

Rainbow trout had a significant influence ($F$ = 23.4; df = 3,24; $P$ < 0.001) on the behavior of Little Colorado spinedace (Figure 1). Significantly more Little Colorado spinedace used undercut banks (mean, 77%; SE, 5.3) in enclosures without rainbow trout than in enclosures with rainbow trout (mean, 44%; SE, 4.1). As a result, significantly more Little Colorado spinedace used open water habitats in enclosures with rainbow trout (mean, 52%; SE, 4.2) than without rainbow trout (mean, 21%; SE, 4.7). These data suggest that rainbow trout cause Little Colorado spinedace to move into open water, which may make them more vulnerable to visual predators. Rocks and vegetation were least used by Little Colorado spinedace, and there were no significant differences in use of rocks or vegetation in either treatment. Furthermore, there were no significant differences in habitat use by Little Colorado spinedace between early morning, midday, and late afternoon.

Little Colorado spinedace tended to group together in loose schools in all cages, regardless of the presence of rainbow trout. Some fish, when approached by larger fish, would display a "flipping" motion. This consisted of a dorso–ventral inversion that flashed the silvery side of the fish to the intruder. No attacks were observed, and it was unclear what purpose this served; however, it was clear how conspicuous the "flipping" behavior would be to a predator like rainbow trout.

The high vulnerability of Little Colorado spinedace to predation by rainbow trout, even in the presence of natural refuges, suggests limited selective predation pressures on Little Colorado spinedace through evolutionary time (Miller 1963). Prior to the introduction of exotic salmonids, Little Colorado spinedace probably used many of the habitats throughout the Little Colorado river drainage now occupied by rainbow trout. The Little Colorado spinedace is highly adapted to the periodic harsh conditions that exist in arid southwestern lotic ecosystems, including high summer temperatures, elevated salinities, periodic torrential floods, high suspended sediments, and changing food resources (Minckley and Carufel 1967; Blinn et al. 1981; Blinn and Runck 1990; Rinne and Minckley 1991). Therefore, Little Colorado spinedace probably encountered limited selective predation pressures by nonnative fishes like that of rainbow trout until recent introductions, which may have occurred in the mid-1800s (J. Novy and B. Silvey, Arizona Game and Fish, personal communication). The introductions of nonnative salmonids have forced Little Colorado spinedace to retreat to suboptimal habitats in the Little Colorado River drainage in Arizona. These suboptimal habitats are relatively free of predators such as rainbow trout and are reduced in number.

The remaining suboptimal habitats that may provide a refuge of last resort for the Little Colorado spinedace in Nutrioso Creek, and perhaps in many shallow lotic ecosystems in the southwestern USA, are those with high turbidity. Aquatic ecosystems with high suspended sediments reduce reactive distances of fish predators (O'Brien 1979), and frequently restrict salmonids (Sorenson et al. 1977; Newcombe and MacDonald 1991). Although aquatic ecosystems with high turbidity may provide a transient refuge for Little Colorado spinedace, these habitats typically have limited food resources and therefore provide marginal habitats for long-term maintenance of populations of this species.

The inverse relationship in spatial distribution of rainbow trout and Little Colorado spinedace in Nutrioso Creek may be caused by the high turbidity in the pools of lower Nutrioso Creek during the summer months. Presently, the habitats with populations of Little Colorado spinedace commonly have high suspended sediments during certain seasons (Blinn et al. 1981; Minckley 1984; Blinn and Runck 1990).

Our results indicate that predation by rainbow trout influences the intrastream (habitat) and, perhaps, the interstream (geographic) distributions of Little Colorado spinedace in Nutrioso Creek, Arizona, and possibly in other drainages where populations of the two species overlap. We recommend that stocking programs be scrutinized and that consideration of native fishes and the functionality of potential refugia be considered prior to future stocking activities.

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